Stated Preferences for Space Heating Investment

Elena Stolyarova, Hélène Le Cadre, Dominique Osso, Benoit Allibe

Stated Preferences for Space Heating Investment

Elena Stolyarova[1,2,*], Hélène Le Cadre[2], Dominique Osso[1], Benoit Allibe[1]

Abstract

Energy retrofits are an important leverage to reduce energy consumption in dwellings, especially for space heating. In this paper, we use a discrete choice experiment on space heating for both detached houses and apartments in France. In our choice experiment, we asked 1,820 respondents, both owners and tenants, to imagine that their current space heating system had broken down and that they had to choose a new one to replace it. A multinomial logit model was used to analyze the households preferences and willingness to pay for various space heating system attributes. We found that in general households prefer renewable sources and systems, but avoid wood. Preferences for familiar technologies have a considerable impact on the probabilities of choice and could represent a significant obstacle to the development of energy-efficient equipment. Willingness to pay for attributes that control energy consumption depends on thermal comfort preferences. The more cold-sensitive the household, the more willing it is to invest to renewable energy sources and to set temperature management.

Keywords: Space Heating, Household Behavior, Choice Experiment, Multinomial Logit, Willingness to Pay

JEL classification: C25, C90, D12, Q40, Q55

1. Introduction

Space-heating energy consumption in residential buildings accounts on average for 15% of total energy consumption in France (ADEME, 2014). In order to reduce this figure, the government has improved thermal regulations and set up financial incentives to encourage the installation of energy-efficient equipment. Policy-makers need quantitative tools to ensure that incentives are effective and to understand household behavior, which can reduce the impact of measures. The purpose of this paper is to investigate the preferences of French households when choosing space-heating systems and the impact of energy conservation measures on these choices (e.g. financial grants, renewable sources or innovative smart technologies).

Discrete choice models, especially when applied to Stated Preferences (SP) data, offer a substantial framework to analyze consumer preferences. Revealed preferences data, which are more accessible and widespread, observe the actual choices of consumers in real-life situations, but rarely provide information about the alternatives not selected and the context of choice. This is particularly the case for data on energy uses in France. INSEE[3] publishes regular data from the National Housing Survey, which comprises a wide range of variables and covers about 40,000 main residences (INSEE, 2006). However, these data give no indication of energy-related household decisions, their motivations and preferences. SP data can fill this knowledge gap. SP data are obtained from a discrete choice experiment, i.e. individual respondents' statements about their preferences in a hypothetical choice situation involving a limited number of offers. The offers were designed by the researcher and are distinguished from each other by characteristics (attributes). The experiment can also include non-existent or rare offers.

*Corresponding author
Email address: elena.stolyarova@edf.fr (Elena Stolyarova)
[1]EDF R&D, ENERgie dans les BAtiments et les Territoires, av. des Renardières – Ecuelles, 77818, Moret sur Loing, France
[2]MINES ParisTech, PSL Research University, CMA, CS 10207 rue Claude Daunesse, 06904, Sophia-Antipolis, France
[3]French National Institue for Satististics and Economic Research (in French: *Institut National de la Statistique et des Etudes Economique*).

Discrete choice models are already widely used in the context of residential building. Achtnicht (2011), Michelsen and Madlener (2013) investigate the choice of energy retrofits in Germany. Archtnicht focuses on CO2-saving measures (heating systems and insulation) and Willingness To Pay (WTP) for each increase of 1% of CO_2 savings. While Michelsen and Madlener examine the factors that impact on the choice of Residential Space Heating System (RSHS). Banfi et al. (2008) measure WTP for energy-saving measures as % of rental prices for apartements and purchasing price for houses, i.e. windows, wall insulation and ventilation. Phillips (2012) is interested in information asymmetry and preferences for insulation, double-glazing and space heating in New Zealand for both owner and landlords. She obtain the distribution of WTP for saving measures with a high taste variation (e.g. the WTP for loor insulation varies between $ -2,000 and $ 6,000. Farsi (2010) studies the risk aversion of Swiss households in rental apartments and calculate WTP as % of rental prices. Kwak et al. (2010) conduct a discrete choice experiment to estimate the WTP for air-conditioning and energy-saving measures (window, faade, and ventilation) in Korea and infer the measures of WTP expressed in terms of increase the thickness and glasses. Rouvinen and Matero (2013) analyze the adaptation of different RSHS in Finland.

In this paper, we present the results of a choice experiment whose aim is to investigate French households preferences and measure WTP for RSHS attributes. By comparison to the above-mentioned studies, we analyze a wide range of choice attributes that comprise standard attributes (investment, saving potential, type of RSHS), financial support for energy retrofits, and indoor temperature control. We also take into account households current situation, i.e. sensitivity to thermal comfort, perception of price signal to evaluate the quality of retrofit and preferences for familiar technologies (type of RSHS, energy source, and management of indoor temperature). The rest of this paper is organized as follows. Section 2 describes the econometric approach and methodology for experimental design. The data is presented in Section 3, followed by the estimation results in Section 4. Finally, some concluding remarks are made in Section 5.

2. Methodology

2.1. Design of choice experiment

To our knowledge, no choice experiment has been published on households RSHS choices in France. We decided to conduct a large choice experiment to include a representative sample of French households. The main target population is homeowners, to which we added tenants. Obviously, tenants cannot take a decision without prior agreement from their landlord and they have little long-term interest in investments. However, they pay energy bills and may be interested in taking part in energy-efficient retrofits, and so landlords may consider their preferences. We therefore wanted to investigate whether owners energy-related preferences differ from tenants. We excluded social tenants living in HLMs[4], because decision-makers in the HLM sector decide for the whole building and have other motivations (or obligations) for investing in energy retrofits.

Two types of situation linked to retrofits can be distinguished. The irreparable failure of an RSHS constitutes an opportunity to install a very efficient space heating system, given that considerable investment cannot be avoided. The second situation is a decision whether to invest in energy retrofits (new RSHS, insulation, etc.) without any obligation. We investigated both types of choice situation, but this study focuses only on the choice of RSHS in order to replace an old system. A wide number of attributes is considered and grouped into two sub-situations to make the choice task easier and investigate some attributes that cannot be used in the same choice situation (e.g. energy source and type of RSHS). Two choice sub-situations are characterized by:

1. Type of RSHS, guarantee and type of setting for indoor temperature.
2. Energy source and financial support (grant for energy efficiency, loan).

[4]Rent-controlled housing (in French : *Habitation à Loyer Modéré*).

Figure 1: Example of choice set used in sub-situation 1

	Offer A	*Offer B*	*Offer C*
Installation costs	€ 10,000	€ 5,000	€ 10,000
Reduction of current energy bill	40%	10%	10%
Space heating system	Wood burning stove	Wood burning stove	Gas boiler
Warranty period against breakdown	4 years	4 years	None
Setting for indoor temperature	Programmable	Remote control	Programmable
CHOICE			

Table 1 describes the attributes, their levels and the choice situation in which the attributes are used. Figure 1 shows an example of a choice set in which the respondent must choose one offer from three space-heating systems. The first situation has $4^4 \times 3$ possible combinations of attributes to form the choice sets, the second situation has $4^5 \times 2^2 \times 3$ combinations. It is impossible to implement all combinations in a reasonable number of choice sets and to present them to each respondent. We use fractional factorial design to determine the best fraction to capture all main effects (Louviere, 2000). Final fraction has 48 choice offers for each sub-situation. We use balancing orthogonal arrays. Balancing means that all levels of all attributes appear the same number of times. Orthogonal means that attributes are uncorrelated. Each respondent makes only one choice out of three offers per situation. We use random draws from 48 offers without replacement to ensure that all 48 offers appear the same number of times. In total, each of the 48 offers was presented to about 125 respondents.

2.2. Attributes

Investment

The level of investment (up-front costs) varies from €5,000 to €20,000 for detached houses and from €3,000 to €15,000 for apartments. Considering a random draw to compose the choice set, it is possible that some respondents will have to compare one offer with €5,000 (or €3,000) of acquisition costs to two other offers each with an investment of €20,000 (or €15,000 in the case of apartments). In order to investigate respondents reaction to this investment opportunity, we observed how respondents reacted to very low prices. The new cross-variable captures the reaction to the very cheapest offer (€5,000 compared to €20,000 and €3,000 compared to €15,000).

Reduction of energy bill

The savings potential is expressed as a percentage of the current energy bill. We asked the respondents to indicate their energy bills for the last year, but these answers cannot be used to estimate the monetary savings due to a high risk of error. Moreover, some respondents did not know the exact amount of their annual energy bill. The first choice sub-situation specifies a particular saving potential for Direct Electric Heating (DEH) of between 5% and 20% compared to a 10% – 55% range for other RSHSs. This revision is because the efficiency limit of DEH is already close to one, compared to the potential efficiency performance of heat pumps or wood burning stoves, which have room for improvement. As the exact amount of energy expenditure is unknown, we cannot deduct and use the payback period for investment as a choice attribute. We could have included it in the experiment design phase, like in Islam and Meade (2013) and Achtnicht (2011). However, the payback period as an attribute may lead to bias in two ways. First of all, the payback period implies a corresponding energy bill amount, which may be completely unrealistic. For example, the offer with investment costs of €20,000, 25% savings potential and 10 years payback period, implies an €8,000 annual space heating bill. Lastly, a household may not think in terms of payback investment when making real-life decisions. In this case, including the payback attribute in an experiment can encourage households to decide according to payback period and so introduce a bias in the results.

Residential Space Heating Systems

The RSHS attribute has four levels. First of all, we include electric and gas RSHSs, which are the most widespread forms of space heating in France and are present in respectively 33% and 48% of dwellings (ADEME, 2014). Electric heating is represented in the attribute by DEH, and heat pumps. While gas is represented by Gas Boiler. We also introduce the wood-burning stove because it is the most dynamic segment of the wood RSHS market (ADEME, 2014). The number of dwellings using wood-burning stoves as their main RSHS increased from less than 1% in 2006 (INSEE, 2006) to 4% in 2013 (ADEME, 2014). Wood-burning stoves are proposed in offers to not only households living in detached houses, but also households living in apartments, which may seem surprising at first glance. However, it is technically possible to install wood burning stoves in apartments, and examples exist[5]. We decided to not specify the exact type of RSHS. The target population of the survey is broad and includes households that intend to invest in energy retrofits as well as those that do not. The former are likely to have sought information about RSHSs and thus be familiar with the specific technical vocabulary involved, whereas the latter are not. When specifying an exact type of RSHS (e.g. air-to-water heat pump, pellet-fire boiler, condensing boiler, heat-emitting panels), we tend to use technical vocabulary. This can be difficult for non-familiar households to understand and, as a result, they may randomly choose the proposed RSHS[6]. In a pre-questionnaire we asked the respondents to indicate the current main RSHS installed in their dwelling and to rate the statement ”I prefer to choose a familiar RSHS”, from ”fully agree” to ”completely disagree”. Crossing the result of these answers with RSHS attributes, we obtained the new attribute ”preference to keep the same RSHS”.

Energy source

The RSHS attribute supposes electricity for DEH and heat pumps, gas for gas boilers, and wood for stoves. However, we are also interested in households generic perception of energy sources. As for the RSHS attribute, we use Electricity and Gas as levels plus Renewable Energy Source (RES) and Wood. Wood is presented separately from RES to capture the potentially different perception of Wood and RES. As in the case of RSHS attribute, we create a new variable crossing the energy attribute and the current energy used for space heating as a main source: 1 if the offer proposes the energy already used for space heating, 0 otherwise.

Setting the indoor temperature

The set temperature can be adjusted by households in order to obtain the desired indoor temperature and/or to reduce energy consumption, e.g. reduce set temperature during the night. Our offers include four types of setting control:

1. None or manual – households must change the setting every time they wish to reduce or increase the indoor temperature.
2. Programmable – this thermostat lowers the temperature at night and during the day when the dwelling is unoccupied.
3. Remote control – the household does not have to be in the dwelling to change the set temperature. The desired level of indoor temperature can be controlled remotely by the household or network operator.
4. SMART – smart control anticipates the weather and periods of dwelling occupation.

We want to take into account the current set control (or absence) used in dwelling. The new cross variable ”New control of set temperature” is: 1 if it proposes a new set control (Programmable, Remote, SMART), 0 otherwise.

Warranty

Some offers propose a warranty against breakdown during the first 2 or 4 years. We estimate that a longer warranty period, such as 10 years, is highly unlikely and costly for the companies that install the RSHS. Moreover, RSHS equipment manufacturers include a manufacturing defect warranty in their selling price.

[5] 154,000 households living in apartment use wood (stove, chimney) for space heating (CEREN, 2014).

[6] Although limiting technical vocabulary, some households described the survey in comments as a very technical, which provides lots of new information and needs more concentration than non-experimental questionnaires.

Financial grants and loans to support energy retrofits

Financial aid/grants are expressed as a combination of three attributes: origin of grant (or type), amount and availability. The sustainable development tax credit[7] and reduced rate of VAT (Value Added Tax)[8] are presented in the attribute ”Grant origin” as the level ”Tax aid”. In 2008, the tax credit was the most popular financial grant. However, its popularity is declining due to the decreased amount and more restrictive conditions (OPEN, 2014). In 2008, 45% of households that invested in retrofits declared that the tax credit was a decisive factor, against only 12.4% in 2013. We also introduce grants from: the local community, energy utility company and the National Agency for Housing, which offers a range of grants. The grant amount has four levels, coded in percent of up-front costs and expressed in euro. Lastly, we use grant availability: immediately, or one year after the retrofit (e.g. in the case of tax credit). In addition to grants, we propose three levels of loan: no loan, interest-free loan and 4% rate loan.

Energy performance certificate

In the second situation, some offers propose to perform the Energy Performance Certificate (EPC) for the dwelling before the energy retrofit.

Table 1: Description and levels of the choice attributes

Situation	Attribute	Description	Levels
1, 2	Investment	Acquisition costs for houses (€)	5000, 10000, 15000, 20000
		Acquisition costs for apartments (€)	3000, 8000, 12000, 15000
1, 2	Reduction	Savings potential as % of current energy bill	10%, 25%, 40%, 55%
1		Savings potential for Direct Electric Heating	5%, 10%, 15%, 20%
1	RSHS	Residential Space Heating System	Gas boiler, Direct Electric Heating, Heat Pump, Wood-burning Stove
1	Warranty	Warranty period against breakdown (years)	0, 2, 4
1	Setting	Control of indoor temperature	None, Programmable, Remote control, SMART
2	Energy	Energy source for space heating	Electricity, Gas, Wood, Renewable Energy Sources
2	Grant Origin	Origin of grant for energy-efficient retrofits	Local community, Tax aid, Energy utility company, National Housing Agency fo Habitat (ANAH)
2	Grant amount	Amount of grant as % of acquisition costs (€)	10%, 25%, 40%, 55%
2	Grant availability	Grant is available	Immediately, after one year
2	Loan	Loan for retrifits	None, Interest-free, 4% rate
2	EPC	Diagnostic of energy performance prior to retrofit	Yes, No

2.3. *Econometric framework*

The discrete choice modeling method, also called Random Utility Models, considers that consumer choice is not determinist and that each good or service in a choice situation may be chosen according to a different level of probability (Thurstone, 1927). The Multinomial Logit (MNL) assumes the homogeneity of preferences among consumers and the independence of irrelevant alternatives (IIA) which implies proportional substitution across labeled choice alternatives (McFadden, 1974). Considering J mutually exclusive offers of RSHS, the utility that a household n derives from offer j in choice situation t is specified as:

$$U_{jnt} = \alpha_t' p_{jnt} + \mu_t'(C_{jnt} T_n) + \beta_t' X_{jnt} + \xi_{jnt} \tag{1}$$

Where α_t is vector of investment parameters (up-front costs in relation to dwelling type), p_{jnt} is the amount of investment, μ_t and β_t are the vectors of parameters associated with non-investment attributes C_{jnt} and X_{jnt}, ξ_{jnt} is a stochastic part of utility that captures the unobserved influence on the individual choices.

We distinguish two types of non-monetary attribute. X_{jnt} – neither monetary nor sensitive to the comfort matrix of explanatory variables, when C_{jnt} – dummy variables for non-monetary categorical attributes which are sensitive to the comfort temperature of household n expressed as the desired indoor temperature T_n. Given that each additional degree of indoor temperature implies an average increase of 7% energy consumption, the energy bill rises in the same

[7] www.vosdroits.service-public.fr

[8] ADEME

proportion *ceteris paribus* (Gossay et al., 2010). So a dwelling heated to 22 °C would consume 28% more than if it were heated to 18 °C. We make the assumption that households pay attention to their increased energy expenditure. The more cold-sensitive a household is and the greater its preference for a warm indoor temperature, the more likely it is to control energy consumption compared to a household with a comfort temperature of 19 °C[9]. First of all, this study has as attribute the type of indoor temperature setting control to reach the comfort temperature at the cheapest cost. However, cold-sensitive households may also be more interested in renewable energy or energy at a cheaper cost (like wood). The estimated parameter μ_t therefore explains household preferences for settings, energy and RSHS for 1 °C of indoor temperature.

$$Pr(U_{j^*nt} > U_{jnt}) = \frac{\exp\left(\alpha_t' p_{j^*nt} + \mu_t'(C_{j^*nt}T_n) + \beta_t' X_{j^*nt}\right)}{\sum_j \exp\left(\alpha_t' p_{jnt} + \mu_t'(C_{jnt}T_n) + \beta_t' X_{jnt}\right)}, \forall j^* \neq j \tag{2}$$

In the MNL model, ξ_{jnt} is independent and identically distributed following the Gumbel Extreme Value distribution. The probability that household n choose the RSHS j is given by a closed-form expression in equation 2 and fitted by Maximum Likelihood estimation.

The use of MNL implies an absence of taste variation across households. This assumption can be considered as highly incredible. In the case of an inappropriate use of MNL, it is preferable to estimate the mixed logit model or latent class model (Train, 2009). In the mixed logit model, the estimated parameters (α_t, μ_t and β_t) follow the density specified by the researcher (e.g. normal, uniform) and are fitted by a simulation of R draws for each decision-maker n. Instead mixed logit model, the latent class model supposes discrete parameter distribution, i.e. the population of decision-maker can be clustered into groups with homogenous preferences. The latent class model is especially interesting in the case of mixture distribution through the population (e.g. two types of household, where one type prefers wood heating while the second type does not). The latent class model is fitted by Expectation-Maximization algorithm.

In order to decide which model is the most appropriate, we estimated the mixed logit model where all non-investment variables are presumed to be random. Using a STATA post-estimation command *mixlbeta*, we obtain the kernel densities for distribution of individual parameters (Hole, 2007*b*). Figure 2 shows an example of kernel distribution for sub-situation 1 from 1000 draws using a mixed logit model. The kernel densities clearly indicates that the non-investment parameters are homogenous for a significant share of respondents, while for the minority of respondents we observe a large variety of individual parameters, especially in the case of wood-burning stoves, for which the individual parameter varies from -10 to 10 in apartments. The use of parametric distribution seems to be completely inappropriate.

After the estimation procedure, we use the results to quantify how much respondents are willing to pay for different attributes of RSHS. The marginal WTP is a ratio of estimated parameter γ for attribute z in sub-situation t to price coefficient α_t:

$$WTP_z = -\frac{\gamma_{zt}}{\alpha_t} \tag{3}$$

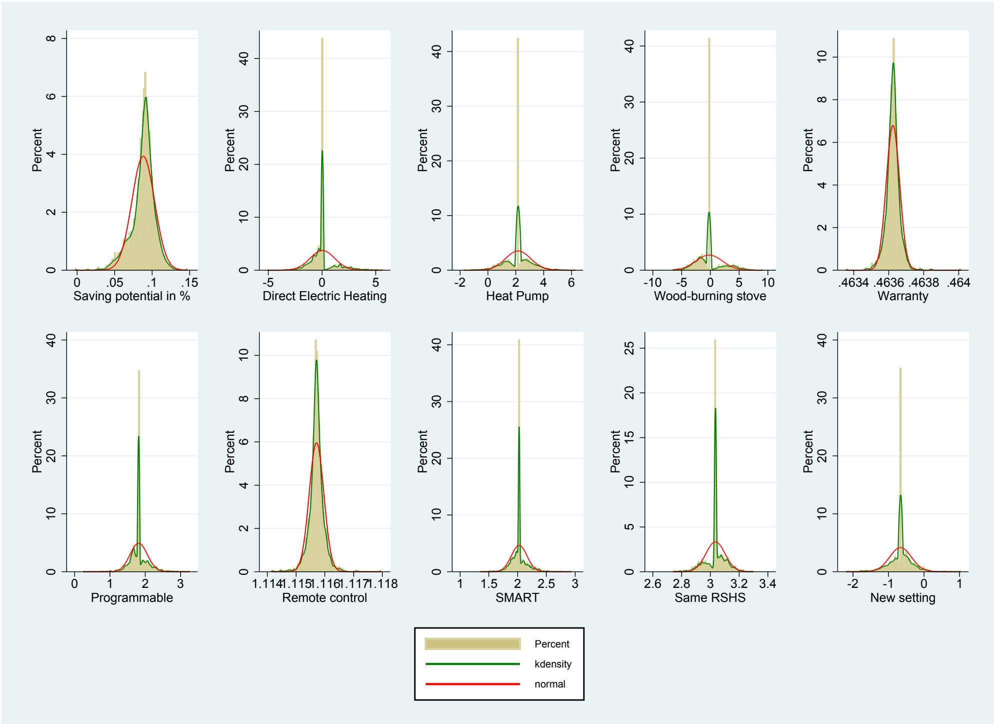
We have two types of non-quantitative attributes. In the case of the simple non-quantitative attribute $X_{jnt} - WTP_z$ is a reservation price, for the comfort sensitive attributes $C_{jnt}T_n - WTP_z$ presents the marginal WTP for an 1 °C increase in comfort level.

3. Data

In order to obtain a representative sample of French households from a large panel, we asked the market research company IPSOS to carry out the survey. Data for the survey were collected from January 16 to January 20, 2015. A

[9]The average level of indoor temperature prescribed by French government (decree n° 79907, October 22, 1979).

Figure 2: Kernel distribution of the individual-level coefficients (sub-situation 1, 5000 draws)



total of 12,600 invitations were emailed with a link to the CAWI[10] survey. In total: 4,542 respondents were excluded at the outset in order to satisfy the quotas methods or because they were inappropriate (e.g. social tenants and households living neither in a detached house nor an apartment), and 6,058 respondents did not complete the survey. The total response rate was 23.83%.

The survey is in three parts. The pre-questionnaire consists of questions on household and dwelling characteristics, thermal comfort perception and energy use. Some descriptive statistics are given in table 2 and 3. About 40 percent of dwellings have access to the gas grid and so can use different types of gas boiler to heat space. The dwellings possess good thermal insulation: 90% are equipped with double-glazing windows and about 70% have partial or total wall insulation. Detached houses seem to be better insulated than apartments. Individual boilers are the most popular type of RSHS (44.1%) in detached houses followed by DEH (26.6%). DEH is the preferred RSHS choice in apartments (37.3%) followed by collective boilers (31.1%) and individual boilers (25.4%). Thermal discomfort, i.e. when current indoor temperature is different from the expected comfort temperature, affects 20% of households living in apartments and 10% of households living in detached houses. The mean indoor temperature in the living room is 19.84 °C, while the mean indoor temperature in bedrooms is one degree lower (18.31 °C). The average household comprises 2.65 people in detached houses and 1.8 people in apartments. The average respondents age is 46–49.

The experimental part of the survey consists of 5 discrete choice situations. In this study, we focus on two choice situations which ask respondents to imagine that their RSHS has failed beyond repair. The situations propose three offers of different types of RSHS. Several details were included to make sure that the offer descriptions had the same meaning for all types of respondent or dwellings; and were the closest to objective reality. We stipulated that respondents do not have to pay a housing loan, i.e. they are homeowners of the occupied dwelling and must replace the individual RSHS with another individual RSHS. The RSHS failure is noticed before the winter heating period and

[10]Computer-Assisted Web Interviewing

Figure 3: Are you ready to undertake these actions with the sole purpose of environmental preservation?

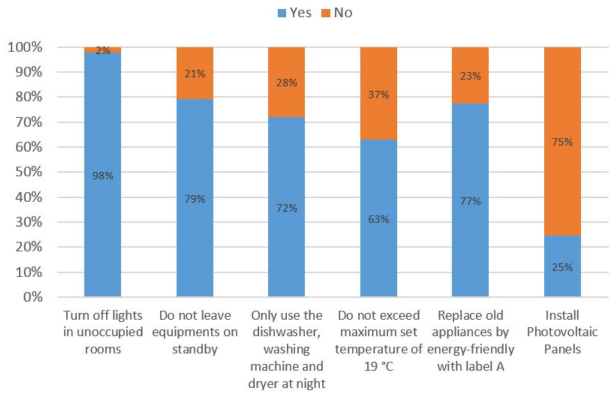
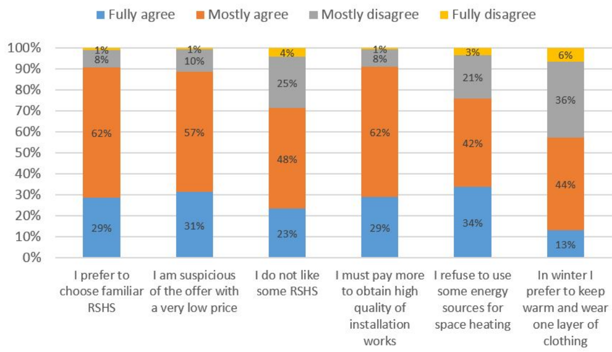


Figure 4: For each statement, do you agree?



the household has enough time to choose and install a new RSHS. The dwelling has access to all energy sources. This detail is not realistic at the moment, for example only 41% of the sample have access to the gas grid. However, we can easily imagine a future extension of access to all energy sources.

The last part of the survey is the respondents perception and attitudes to energy (Figures 3 and 4). Almost all respondents are prepared to turn off lights in unoccupied rooms (98%), not leave appliances on standby (79%) and replace old appliances with energy-saving ones (77%). 28% of respondents do not accept changing their habits to use dishwasher/washing/dryer machines at night. Some inhabitants of apartments do not accept this measure to avoid disturbing their neighbors. More than half of the sample respondents are prepared to not exceed the set temperature of 19 °C (63%). In our sample, 27.96% of respondents stated a comfort temperature of 19 °C or less, 34.7% prefer 20 °C and 37.29% prefer 21 °C or more. The price signal of investment in space heating is very important for respondents: 91% are willing to pay more to ensure the quality of retrofit work and are suspicious of very low prices. Slightly more than half of respondents prefer to heat their dwelling to a warm temperature and wear only one layer of clothing.

Table 2: Summary of continuous characteristics

Variable	Min	Mean	Max	Std. dev.
Number of inhabitants (house)	1	2.65	7	1.18
Number of inhabitants (apartment)	1	1.8	7	0.94
Living area in m^2 (house)	38	123	450	55.9
Living area in m^2 (apartment)	10	66.5	300	29.3
Indoor temperature °C (living room)	15.5	19.84	24.5	1.35
Indoor temperature °C (bedroom)	15.5	18.31	24.5	1.27
Comfort temperature °C	16.5	20.1	24.5	1.27
Respondent age (house)	18	49.9	75	16.1
Respondent age (apartement)	18	45.8	75	17.2

Table 3: Summary of the socio-demographic and dwelling characteristics (in %)

	Dwelling type		
	Total	House	Apartment
No access to gas grid	61.7	64.8	55.6
No double-glazing	10.8	5.9	18.9
Partial or total wall insulation	69.7	79.7	53.1
Thermal discomfort	13.7	9.9	19.8
Income per month in euro			
< 1200	5.6	3.1	9.7
1201–1900	19.1	13.7	28.1
1901–2700	19.9	20.9	18.1
2701–3800	24.0	27.4	18.5
> 3800	19.7	22.6	14.9
Confidential	11.7	12.3	10.7
Occupancy status			
Owners	72.7	87.4	48.5
Tenants (without social tenants)	27.3	12.6	51.5
Age of dwelling			
pre-1974	39.7	38.1	42.4
1974-1989	23.4	25.1	20.7
1990-1998	8.9	9.6	7.9
post-1998	23.9	25.9	7.6
unknown	4.1	1.4	8.3
Dwelling type			
Detached house	62.3	–	–
Apartment	37.7	–	–
Urban density			
Rural	19.5	29.9	2.3
Urban	65.5	63.2	69.4
Paris area	15.0	6.9	28.3
Climate zone			
Mediterranean	13.6	12.5	15.4
Middle oceanic	10.4	12.7	6.7
Oceanic	10.6	13.1	6.5
Fresh oceanic	12.0	13.7	8.4
Modified oceanic	33.2	26.1	44.9
Semi-continental	11.5	13.1	9.5
Mountain	8.7	8.8	8.6
Space heating system			
Individual boiler	37.0	44.1	25.4
Collective boiler	12.2	0.7	31.1
Heat pump	7.0	10.8	0.8
Direct electric heating	30.7	26.6	37.3
Chimney and wood stove	9.2	14.5	0.4
Other	3.9	3.3	5
Setting of indoor temperature			
None	45.2	40.9	52.2
Programmable	41.9	51.9	25.5
Remote control	1.9	2.5	1.2
SMART	3.3	4.4	0.9
Setting at the building level	7.3	0.2	18.9

4. Results and discussion

A total of 1,802 respondents were selected to take part in the econometric estimation. The results for each choice sub-situation are given in Table 4. All models have a good overall fit, measured as pseudo ρ^2, knowing that ρ^2 between 0.2 and 0.4 are equivalent to R^2 between 0.4 and 0.9 in linear regression models (McFadden, 1974). All attributes from the experiment design are significant and impact the respondents choices. The investment coefficients have an expected negative sign: respondents prefer the cheaper offer *ceteris paribus*. As expected, the estimated coefficient for an energy bill reduction is positive.

The new created cross-variables are significant in both sub-situations. Households prefer offers with the same type of RSHS and energy source as they already use. These attributes have the greatest influence on household choices. The associated coefficients in sub-situation 1 and 2 are: 0.447*** if the offer contains the same type of RSHS and 0.046 (must be multiplied by comfort temperature) if the offer proposes the energy already used by household. Similarly, if the offer proposes a new setting to control indoor temperature, the probability of being selected decreases. The price signal also has a high impact on the choice set with the cheapest offer €3,000 – €5,000 against €15,000 – €20,000 for the other two offers.

Table 4: Estimation results from MNL Model

Attribute	Situation 1	Situation 2
Investment in house (by €1,000)	-0.106 (0.008) ***	-0.093 (0.001) ***
Investment in apartment (by €1,000)	-0.172 (0.014)***	-0.151 (0.014)***
Reduction (by 1%)	0.034 (0.002)***	0.0313 (0.002)***
Best investment × Price signal	0.237 (0.095)**	0.198 (0.103)**
Same RSHS × Prefer familiar RSHS	0.447 (0.038)***	
Type of RSHS		
Natural gas boiler	0	
DEH × Comfort temperature in °C	0.004 (0.107)	
Heat Pump × Comfort temperature in °C	0.038 (0.005)***	
Wood-burning stove (house) × Comfort temperature in °C	0.015 (0.006)***	
Wood-burning stove (apartment) × Comfort temperature in °C	-0.023 (0.008)***	
Warranty (by 1 year)	0.176 (0.02)***	
New setting × Comfort temperature in °C	-0.018 (0.007)***	
Control of set temperature		
None	0	
Programmable × Comfort temperature in °C	0.035 (0.006)***	
Remote control × Comfort temperature in °C	0.029 (0.008)***	
SMART × Comfort temperature in °C	0.041 (0.008)***	
Same energy source × Comfort temperature in °C		0.046 (0.004)***
Energy source		
Natural gas		0
Electricity × Comfort temperature in °C		0.029 (0.004)
RES × Comfort temperature in °C		0.039 (0.005)***)
Wood (house) × Comfort temperature in °C		-0.004 (0.005)
Wood (apartment) × Comfort temperature in °C		-0.021 (0.007)**
Grant origin		
Local community		0
Tax aid		0.275 (0.089)***
Energy utility company		0.07 (0.091))
ANAH		0.097 (0.09)
Grant amount		0.16 (0.042)***
Grant availability		
After one year		0
Immediately		0.26 (0.064)***
Loan		
None		0
Interest-free rate		0.482 (0.09)***
4% rate		0.031 (0.08)
EPC (house)		0.068 (0.078)
EPC (apartment)		0.531 (0.111)***
Pseudo ρ^2	0.2292	0.1764
Log-likelihood	-1525.91	-1630.47
Observations	1802	1802

Asterisks denote statistical significance on the *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$
Standard errors are given in parentheses

4.1. Focus on some attributes of RSHS choice

Investment costs

The level of investment varies according to dwelling type. It is important to disassociate the investment effect of detached houses from apartments. Obviously, households living in apartments would pay less than those in detached houses. The estimation results support this expectancy: estimated coefficients for investments in apartments are 1.62 times higher than in houses. If the acquisition costs increase by €1,000 for an offer, then the probability of being chosen decreases 60% faster for apartments than for detached houses. The cross-variable, called *Best Investment × Price signal*, which indicates the reaction to a very wide gap between the cheapest offer and another, shows that households are distrustful towards very low prices. According to Figure 4, 87% of households fully or mostly agree that the offer with the cheapest price is suspicious and probably indicates low installation quality. These people will avoid the cheapest offer. We conclude that French households pay great attention to disparity of investment to ensure the quality of RSHS installation. Should they rely so heavily on the price signal? The answer depends on the motivation of the heating installer. Knowing that the French retrofit market is mainly comprised of local oligopolies with limited competition, we tend to conclude that heating installers send out no price signal , or worse still, an opposite price signal. Generally in France, heating installers belong to very small companies[11] with potential difficulty accessing to the whole market. Thus, in the case of an unknown RSHS linked to an enhanced risk, an installer might increase the investment cost to hedge the risks related to an installation considered as complicated. In this case, the quality of work potentially decreases as prices increase, which is the opposite of what households expect.

Residential Space Heating Systems

The gas boiler is the base category (value is fixed to be 0), and so the other considered RSHSs must be compared to the gas boiler. The results indicate that households are indifferent between gas boilers and DEH for which the estimated coefficient is not significant. The heat pump is the preferred choice followed by the wood stove in detached houses. Apartment residents do not opt for wood stoves (-0.023*** by 1 °C of comfort temperature). Some apartment households may think that stoves are not compatible with their dwelling type or consider that they do not have enough space to stock wood (logs, pellets).

Energy source

The results are quite similar to the RSHS attributes. Natural gas is the base category. Households in detached houses are indifferent between gas, electricity and wood. The non-significance of the wood coefficient can be explained by the different types of wood heating system. In apartments, households are indifferent between gas and electricity, and wood is the last choice. For both types of dwelling, households have a strong preference for renewable energy sources (RES). This preference seems to be inconsistent with results for wood, which is also an RES. Households may distinguish wood from other renewable sources probably due to the burden of wood supply and storage.

Warranties and energy performance certificates

All households prefer offers with warranties against breakdown. Each warranty year in the offer increases the probability that it will be chosen by 0.176. The perception of EPC attributes depends on the dwelling type. Residents of detached houses are indifferent to EPC attributes, while apartment residents are very interested in offers with EPC. The different perception of the EPC attribute may indicate that households in apartments lack information on their dwelling energy performance and think that such information could help them to reduce energy bill for example.

Control of indoor temperature

Households prefer offers that propose control temperature setting. SMART control is the most popular setting, followed by programmable thermostats. Remote control is the least popular setting. As remote control can be managed by third parties, some households may reject this technology due to data privacy concerns, considering that it is an invasive setting.

[11] 327,000 companies (craft industry with less than 10 employees) and 470,000 employees (FFB, Les chiffres clés de l'artisanat du bâtiment, 2010).

Financial grants and bank loans

Households prefer a tax rebate to other grants, to which they are indifferent. The amount of the grant has a multiplicative effect on investment. The invest coefficient for each €1,000 are -0.093 in detached houses and -0.151 in apartments. Each €1,000 of grant increases by 0.16 the probability that the offer considered will be chosen. This means that each €1,000 of grant encourages households to invest more than €1,000 in RSHS, especially in the case of detached houses. The availability of a grant has a positive impact on the probability that an offer will be chosen.

4.2. Willingness-to-pay measures

Table 5: Willingness to pay in €for choice situation 1 (mean and confidence interval)

	Detached houses			Apartments		
Attribute	**WTP**	Lower limit	Upper limit	**WTP**	Lower limit	Upper limit
Reduction 10%	**3249**	2650	3848	**2000**	1620	2390
Same RSHS	**4318**	3427	5210	**2661**	2081	3241
DEH at 19 °C	**716**	-1146	2813	**441**	-708	1736
Heat Pump at 19 °C	**6811**	5302	9329	**4197**	3222	5795
Wood-burning Stove at 19 °C	**2688**	-504	3698	**-2540**	-4115	163
Programmable at 19 °C	**6293**	4044	8541	**3878**	2470	5286
Remote control at 19 °C	**5215**	2330	8099	**3213**	1428	4999
SMART at 19 °C	**7339**	4395	10283	**4523**	2708	6337
New set control at 19 °C	**-3489**	-5846	1132	**-2150**	-3599	-701
Guarantee (per year)	**1660**	1227	2092	**1023**	752	1293

In this section we discuss WTP in order to obtain a monetary valuation of household preferences. Moreover, WTP allows the researcher to compare the different discrete choice models. Indeed, the variance of error term ξ_{jnt} in discrete choice models is normalized to $\pi^2/6$ which leads the estimated coefficient to be scaled by $1/\sigma^2$ where σ^2 is the real variance of the model. As the models have distinct real variances, the estimated parameters are scaled by different ratios. Thus, the use of WTP measures removes the scale ratio from coefficients and the models can then be compared (Train, 2009).

Tables 5 and 6 show the WTP measures for each sub-situation model. The lower and upper limits of WTP indicate a possible WTP limit of 95% confidential interval calculated with the delta method (Hole, 2007*a*). Although the gap between the lower and upper limits is wide, the kernel distributions of individual level parameters in Figure 2 suggest that the WTP measures are concentrated on the estimated value of WTP (bold italic in tables).

The WTP for a 10% additional savings potential on the current energy bill is €3,300 in detached houses and €2,000 in apartments. The fact that the WTPs in both models are close shows that the quality of survey design is good and that respondents considered the sub-situations in the same way.

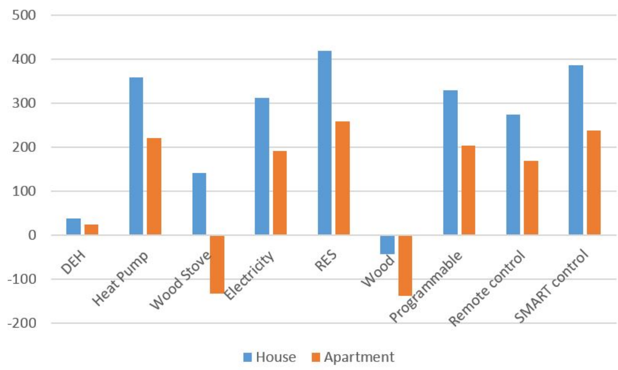
Table 6: Willingness to pay in €for choice situation 2 (mean and confidence interval)

	Detached houses			Apartments		
Attribute	**WTP**	Lower limit	Upper limit	**WTP**	Lower limit	Upper limit
Reduction 10%	**3346**	2577	4115	**2079**	1642	2516
Same energy at 19 °C	**9246**	6709	11782	**5746**	4256	7235
RES at 19 °C	**7998**	5527	10469	**4970**	3497	6444
Wood at 19 °C	**-901**	-3061	1259	**-2658**	-4562	-753
Grant availability	**2752**	1377	4126	**1710**	840	2580
Interest-free loan	**5155**	3054	7255	**3096**	1486	4706
4% rate loan	**332**	-1338	2002	**206**	-832	1245
EPC	**732**	-919	2382	**3523**	1966	5081

Households are willing to pay €4,300 (€2,661)[12] to buy the same type of RSHS that they currently use, and €9,246 (€5,746) to keep the same energy. These strong preferences for accurate RSHS and energy sources is a barrier

[12] For the remainder of this article the value of WTP in parentheses is a WTP for apartments.

Figure 5: The WTP values per 1 °C of comfort temperature



to new energy-efficiency RSHS, especially wood heating systems. While installing a heat pump is more acceptable for those using electricity heating. The respondents are more willing to invest in a heat pump at €6,800 (€4,150) than to install a gas boiler or DEH. The average investment in detached houses for a condensing gas boiler is €4,300 and €13,500 for an air-to-water heat pump (UFE, 2012). The gap between the two technologies is €9,200, which is higher than the WTP of €6,800 for heating a space to 19 °C in detached houses. Although these households are willing to use a heat pump instead of a gas boiler, but they are not prepared to invest in an air-to-water heat pump at its current price.

The WTP for RES from sub-situation 2 is greater than the WTP for a heat pump: households are willing to pay €8,000 (€4,970) more for RES than for natural gas. However, we think that this value is overestimated because we did not stipulate the potential renewable sources.

The WTP for an indoor set-temperature device is around €6,000 (€4,000) in the first sub-choice situation. This is a very high value that largely covers the current price of €1,000 for a programmable temperature management device (ANAH, 2014). For future research, it would be interesting to investigate the interaction between RSHS/energy attributes and indoor temperature settings.

In the previous sub-section 4.1, we saw that the amount of financial grant has a multiplier effect. In terms of WTP, for each additional €1,000 of grant, households are willing to invest an additional €1,600 in their detached houses. In contrast, apartment residents are willing to invest only €1,061 for each additional €1,000 of grant. For these households, financial grants have not a multiplier effect. In addition, if grants are available immediately, households are prepared to increase the maximum level of investment by €2,700 (€1,710). Loans are not very popular. However, households will use interest-free loans and be willing to invest an additional €5,000 (€3,000).

Offers that include a prior diagnosis of dwelling energy performance (EPC) are of interest to households living in apartments, who are willing to invest €3,500. Inhabitants of detached houses are not interested in EPC.

In this study, thermal comfort is presented through choice attributes that can impact and control energy consumption in the home, i.e. set-temperature device, type of energy and RSHS. Figure 5 presents the WTP values for 1 additional degree of comfort temperature by dwelling type. Households are more comfort-sensitive to renewables: RES, heat pump or wood-burning stove, with respectively €420 (€258), €358 (€221) and €141 (€-133) per additional 1 °C. The sensitivity to temperature setting is: €386 (€238) for SMART setting per 1 °C additional degree of comfort temperature.

5. Conclusion and policy implications

In this study we investigate the choice of RSHS to replace a space heating system that is beyond repair. Two choice experiments were examined to understand and quantify household preferences for RSHS attributes. A multinomial logit model was used to analyze the choice data. The results indicate that households connect the price of RSHS to the expected quality of the installation. The estimation results suggest that French households generally support renewable energy solutions and are willing to pay €5,000 – €8,000 more for RES than for natural gas or electricity. However, when the type of renewable energy or renewable RSHS is indicated, the WTP is lower or, worse still, negative, like in the case of wood and wood stoves (in apartments). Households on average may expect high RES efficiency, or may expect other RES-based systems (e.g. solar). However, when faced with explicit RSHS offers (heat pumps or wood stoves), they revise their preferences downwards. The models clearly show that households only select wood as an energy source in the case of wood stoves in detached houses.

The preferences for adopting a familiar technology (RSHS, energy source, setting of indoor temperature) have the highest impact on RSHS choices. Households generally prefer not to change their habits. This preference for familiar technology is an obstacle to the development of innovative technologies, which is accentuated by the current situation of the RSHS market. In our previous work, we found that dwelling and household characteristics alone can predetermine the type of installed RSHS and that some households have no choice (Stolyarova et al., 2015). From a policy point of view, it is important to reduce these barriers and improve market transparency.

Thermal comfort is not an attribute of RSHS choice, however we note that comfort indirectly impacts choices through the energy bill. Cold-sensitive households are willing to invest more in renewable sources and devices to manage indoor temperature. SMART devices, which can anticipate weather and periods of dwelling occupation, are the most popular system, with an associated WTP of around €3,000 to €7,000 (€1,600 – €4,500). SMART control appears to be an excellent leverage to reduce energy consumption. Liang et al. point out that the anticipation capacity of SMART thermostats makes it easier to obtain a sensation of thermal comfort at cheaper prices (Liang et al., 2012).

References

Achtnicht, M. (2011), 'Do environmental benefits matter? evidence from a choice experiment among house owners in Germany', *Ecological Economics* **70**(11), 2191–2200.

ADEME (2014), Les chiffres clés du bâtiment 2013, Technical report.

ANAH (2014), 'Evaluation du programme Habiter Mieux (synthèse de l'étude 3)'.

Banfi, S., Farsi, M., Filippini, M. and Jakob, M. (2008), 'Willingness to pay for energy-saving measures in residential buildings', *Energy Economics* **30**(2), 503–516.

Farsi, M. (2010), 'Risk aversion and willingness to pay for energy efficient systems in rental apartments', *Energy Policy* **38**(6), 3078–3088.

Gossay, J., Lavaissire, D., Tabardin, J.-F., Lob-Ferraggioli, J., Tranain, C. and Vaujany, F. (2010), 'Logements collectifs surchauffés : comment agir ?', *Institut de l'écologie en milieu urbain* .

Hole, A. R. (2007*a*), 'A comparison of approaches to estimating confidence intervals for willingness to pay measures', *Health Economics* **16**(8), 827–840.

Hole, A. R. (2007*b*), 'Fitting mixed logit models by using maximum simulated likelihood', *Stata Journal* **7**(3), 388 – 401.

INSEE (2006), 'Enquête logement'.
URL: *http:/www.cmh.ens.fr/greco/enquetes/XML/lil-0410.xml*

Islam, T. and Meade, N. (2013), 'The impact of attribute preferences on adoption timing: the case of photo-voltaic (PV) solar cells for household electricity generation', *Energy Policy* **55**, 521–530.

Kwak, S.-Y., Yoo, S.-H. and Kwak, S.-J. (2010), 'Valuing energy-saving measures in residential buildings: a choice experiment study', *Energy Policy* **38**(1), 673–677.

Liang, Y., Levine, D. I. and (Max) Shen, Z.-J. (2012), 'Thermostats for the smart grid: models, benchmarks, and insights', *The Energy Journal* **33**(4).

Louviere, J. J. (2000), *Stated Choice Methods: Analysis and Applications*, Cambridge University Press, Cambridge.

McFadden, D. (1974), 'The measurement of urban travel demand', *Journal of Public Economics* **3**(4), 303–328.

Michelsen, C. C. and Madlener, R. (2013), 'Motivational factors influencing the homeowners' decisions between residential heating systems: an empirical analysis for Germany', *Energy Policy* **57**, 221–233.

OPEN (2014), 'Open campagne 2014: résultats 2013', *ADEME* .

Phillips, Y. (2012), 'Landlords versus tenants: information asymmetry and mismatched preferences for home energy efficiency', *Energy Policy* **45**, 112–121.

Rouvinen, S. and Matero, J. (2013), 'Stated preferences of Finnish private homeowners for residential heating systems: a discrete choice experiment', *Biomass and Bioenergy* **57**, 22–32.

Stolyarova, E., Le Cadre, H., Osso, D., Allibe, B. and Maïzi, N. (2015), 'Residential space heating determinants and supply-side restrictions: discrete choice approach', *CMA Working Paper* .

Thurstone, L. L. (1927), 'A law of comparative judgment.', *Psychological Review* **34**(4), 273–286.

Train, K. E. (2009), *Discrete Choice Methods with Simulation*, 2 edn, Cambridge University Press, Cambridge ; New York.

UFE (2012), 'Un instrument clé de pilotage de la politique énergétique: l'ordre de priorité des actions d'efficacité énergétique'.